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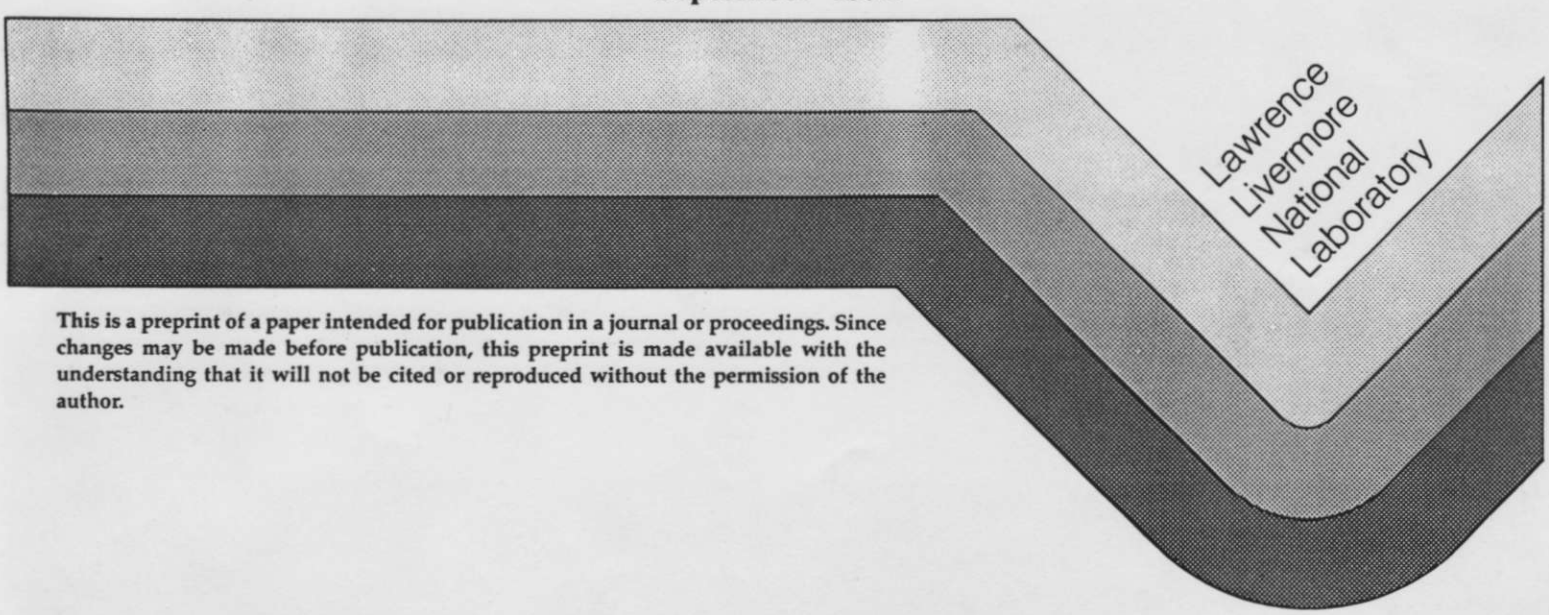

SHOCK-INDUCED MARTENSITIC TRANSFORMATION OF HIGHLY ORDERED GRAPHITE

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We have measured wave profiles in highly ordered pyrolytic graphite shocked normal to the basal plane. For graphite with sufficient orientational order a martensitic transformation is observed with a transition onset pressure near 20 GPa. The two-wave structure of the transition wave profile is overdriven above 40GPa.

1. INTRODUCTION

An outstanding unresolved issue is whether the shock-induced phase transition of graphite to diamond is martensitic or diffusive. The relation between the crystal structures of graphite and diamond indicate that the phase transition should be fast and martensitic if shock pressure is applied perpendicular to the graphitic basal plane. Since the lattice planes of graphite are loosely coupled, small amounts of shear stress naturally existing in the shock state is expected to induce displacive shear motion between the planes so as to produce the diamond stacking sequence.

Recent *static* compression measurements have found that single crystalline graphite begins to transform at 18 GPa[1]. Previous shock studies[2-4] using pressed porous graphite samples have also indicated a phase transition to occur near 20 GPa, but interpretation of the results is complicated by their heterogeneous temperature distribution and possible spatial distribution of transformation mechanism[5]. In contrast, other studies using pyrolytic graphite (a quasi single-crystalline form) have observed phase transitions near 34 GPa[6], 45 GPa[2] or have failed to see it below 50 GPa[7]. Since pyrolytic samples are more ideal crystalline graphite than porous samples, this wide variety of behavior initially seemed contradictory. But recent measurements[8] on pyrolytic graphite of two different grades having different orientational order indicate a strong sensitivity of shock behavior on specimen microstructure. Our studies are the first wave profile measurements using highly ordered full density pyrolytic graphite. Thus our observation of a 20 GPa transition onset pressure and a fast martensitic transition is likely to be representative of crystalline graphite.

2. EXPERIMENTAL

Because the graphite-diamond transition involves a relatively large volume change, the shock-wave emerging from the specimen is expected to have two steps, or a "two-wave" structure, in shock pressure or material velocity[9]. By measuring the amplitudes of the step and the transit time of the shock through the sample, the transition onset pressure (P_{ot}) can be determined.

Shock waves were generated by impact of a Cu disk accelerated by a two-stage light-gas gun striking a graphite specimen normal to the basal plane. The specimen was backed by a LiF window through which a laser beam was reflected off the graphite/LiF interface. Since LiF has a shock impedance similar to graphite, the perturbation of the first shock wave by the interface is relatively small. The laser is the illuminating beam of our VISAR interferometer[10], which measures velocities with a time resolution of 2-3 ns via the doppler shift of the reflected light. The sample was highly oriented monochromator grade (ZYB) graphite from Union Carbide measuring 3.5-4 mm thick and 15 mm square. The densities were 2.254 - 2.259 g/cm^3, very near the handbook value[11] of 2.265 g/cm^3.

3. RESULTS

Well defined two-step wave profiles were observed indicating a polymorphic phase transition from the graphite phase. The transition onset pressure was measured in four shots to be 18.6, 19.3, 19.9, and 20.1 GPa, for a mean of 19.5±0.7 GPa at a compressed density of $\rho = 2.75$. The risetime of the steps in the two-step waveprofile were very rapid (<10 ns) indicating the transformation was

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martensitic. The consistency of the value of P_{ot} between the four shots is a further indication of a martensitic nature of the transformation. The wave profile data show the "textbook" behavior[9] of shockwave splitting due to a polymorphic phase transformation. That is, as the impactor velocity increases from 2.6 km/s the delay between the two waves decreases, until above 3.47 km/s and 40 GPa there is a single overdriven shock.

The second step observed in the two-wave profile is the shock into the phase transformed state. This is determined from the measurements to have densities close to, but slightly less dense than diamond[12] shocked to a corresponding pressure. The difference in densities may be attributed to either thermal pressure or a degree of disorder in the final diamond shocked state. A third possibility is that the phase transformed state is a distorted diamond-like phase (n-diamond) recently recovered[13] from shocked graphite.

4. CONCLUSION

We observe a martensitic shock transformation of highly ordered (ZYB grade) graphite with an onset pressure of 19.5±0.7 GPa. The two-wave waveprofile structure is overdriven above 40 GPa. Since it has been shown[8] that non-martensitic shock behavior can be seen with pyrolytic graphite having less orientational order than ZYB grade graphite, we believe the elevated transition pressures observed with pyrolytic samples of earlier studies[2,6,7] was due to the lack of sufficient order in their microstructure, while their high density prevented significant shock heating which could provide a thermally activated diffusive transformation[14]. The latter effect likely dominated the behavior of pressed porous samples in other studies[2-4], allowing for these P_{ot} near the crystalline graphite value.

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